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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Robert Graham Burrage 1 The Chestnuts Abingdon Oxon OX14 3YN
Patents ADP number *(if you know it)*	8785388001
If the applicant is a corporate body, give the country/state of its incorporation	
4. Title of the invention	Tilt rotor aircraft
5. Name of your agent *(if you have one)*	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	MATHYS & SQUIRE ~~100 Gray's Inn Road~~ ~~London WC1X 8AL~~ United Kingdom 120 HOLBORN LONDON EC1N 2SQ GLOBAL 26.1.05 MW
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Claim(s)	3
Abstract	1
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TILT ROTOR AIRCRAFT

The present invention relates to a convertiplane of the tiltable rotor type.

Background of the Invention

As is known, there are many designs of aircraft, herein referred to as convertiplanes, seeking to combine the advantages of fixed-wing propeller aircraft and of helicopters, for example by use of tilt-rotors or by tilt-wings. Of these, arguably only the twin tilt-rotor designs are close to full production.

Twin tilt-rotor designs have a long history. In 1934, US patent no. 1951817 was granted to Blount for his "airplane-helicopter". In 1958 the Bell XV-3 became the first tilt-rotor to convert to the aeroplane mode; a 15-year test programme proved that it could fly safely and smoothly throughout its flight envelope. The XV-3 was limited in speed by its use of blades designed for helicopter flight, and this was remedied in Bell's next project, the XV-15, by use of high twist blades. The first XV-15 was rolled out in 1976, and by 1986 the two prototypes had achieved an unofficial record for rotorcraft of 301 knots, had accumulated 530 flight hours and made 1,500 conversions. In that year a scaled-up version of the XV-15, a joint proposal by Bell and Boeing called the V-22 Osprey, was approved for full-scale development for the US armed forces, achieving its first flight in 1989. The V-22 eventually entered low-rate initial production in 1999, but subsequently was grounded after two crashes in 2000; revised flight tests began in May 2002 and it is now in limited production.

The most recent twin tilt-rotor is the Bell Agusta BA 609, which made its maiden flight on 7 March 2003 as the world's first civil tilt-rotor and is configured generally as the V-22.

This history from 1934 to the present day shows painfully slow progress for the twin tilt-rotor concept. Over the same timescale a wide variety of helicopter designs have achieved large-scale production and valuable service worldwide. But even that success for helicopters is modest compared to that of fixed wing aircraft which have

achieved production quantities, utilisation, safety, reliability, speed, range and altitude performance that are far better and at much lower cost than helicopters of equivalent payload.

The reasons for the relative success (or lack of it) of these three concepts lie in the economic cost of acquisition and operation.

Firstly, comparing a propeller driven fixed wing design with a helicopter design of equal payload, fuel load and installed turbine power:

- The weight of high cost machinery, ie. powerplant, transmission, rotor or prop blading etc needed by the fixed wing design is half that of the helicopter.
- The fixed wing design would be expected to have twice the cruise speed and much greater range.
- But the helicopter is VTOL capable, whereas the fixed wing design is not.

Second, comparing a twin tilt-rotor design with the above two designs:

- The twin tilt-rotor can be both CTOL and VTOL capable, the other two designs cannot.
- The range of the twin tilt-rotor will be much better than the helicopter but significantly less than the fixed wing design.
- However, in order to match the speed and CTOL capability of the fixed wing design and to match the VTOL capability of the helicopter, the twin tilt-rotor needs twice the installed turbine power.
- The weight of high cost machinery, ie powerplant, transmission, rotor or prop is twice that of the helicopter and four times that of the fixed wing design.

It is an object of at least the preferred embodiments of the present invention to provide a tilt-rotor aircraft in which the above disadvantages are reduced.

The term "rotor" is to be construed broadly, to include not only an open (helicopter-type) rotor, but also a ducted fan or ducted rotor.

In another aspect, the invention provides a tilt-rotor aircraft comprising a fuselage, wings for sustained forward flight, and at least one rotor tiltable between a position providing lift and a position providing propulsion for forward flight, the rotor or rotors being carried by supporting structure mounted on the fuselage and being disposed on or symmetrically about the longitudinal centre line of the aircraft.

In another aspect, the invention provides a tilt-rotor aircraft comprising a plurality of rotors carried by at least one tiltable nacelle on the longitudinal centre line of the aircraft.

The or each nacelle may have a pair of contra-rotating rotors which are coaxial, or on parallel axes, or intermesh.

A said nacelle or supporting structure may be mounted to pivot and optionally also translate about an axis extending transversely of an upper part of the aircraft fuselage.

The nacelle may contain at least one engine. Alternatively the engine(s) may be located elsewhere in the aircraft, and power may be delivered mechanically to the rotors or via a local power turbine, electric motor, hydraulic motor or other transmission.

The rotors preferably are driven by a plurality of engines via a transmission such that all the rotors continue to be driven if an engine fails.

The nacelle may be mounted to pivot and optionally also translate about an axis extending transversely of an upper part of the fuselage.

At least inboard portions of wings of the aircraft maybe moveable so as to present leading edges to the airflow generated from the rotors in lift mode.

In another aspect the invention provides a tilt-rotor aircraft comprising a tiltable rotor assembly on the longitudinal centre line of the aircraft moveable between a lift mode and a forward flight mode, inboard portions of the wings of the aircraft being moveable so as to present leading edges to the airflow generated by the rotors in lift mode.

A said moveable portion may be rotatable and/or translatable transversely or longitudinally about a fixed beam projecting from the fuselage of the aircraft.

The beam may extend to a fixed outboard portion of the wing.

Preferably each wing may have at least two substantially parallel moveable portions.

A said moveable portion may be configured to act as a control surface when the aircraft is in lift mode and/or in transition between lift and forward flight modes, the aircraft also comprising control means for operating the control surface.

The underside of the aircraft fuselage may be shaped to reduce download forces on the fuselage from the airflow generated by the rotor or rotors in lift mode.

Preferably there is a control surface on the fuselage, operative when the aircraft is in a lift mode and/or in transition between lift and forward flight modes.

In a further aspect the invention provides a tilt-rotor aircraft comprising a tiltable rotor assembly moveable between a lift position and a forward flight position in front of or behind the fuselage.

Preferably in this aspect the aircraft is of a twin-boom layout, wherein booms extend rearwardly from the wings of the aircraft to support the aircraft's empennage, the

rotor assembly being behind the fuselage and disposed between the booms when the aircraft is in forward flight mode.

In one embodiment, the rotor assembly is below the fuselage when in the lift position. In another embodiment it is above the fuselage.

The preferred embodiments of the invention have all the powerplant, transmission and rotor components within a single rotornacelle, allowing some components such as cross-wing transmissions to be eliminated and others such as support structures to be simplified.

Other advantages which may be achieved are the following:-

- The co-axial, contra-rotating rotors enable gyroscopic forces and rotor torques to be balanced within the rotornacelle rather than across the aircraft structure.
- Having a single centrally mounted and aerodynamically symmetrical rotornacelle, the aircraft is much less vulnerable to asymmetric airflow and asymmetric thrust. This is a particular concern in low speed and hovering flight. For example a twin-prop airplane that loses all thrust from one side becomes more difficult to manoeuvre or land or take off at low speed, where yaw problems can escalate into irrecoverable roll. Twin tilt-rotor designs typically guard against this problem of asymmetric loss of power by the use of complex cross-wing transmissions between their engines, however this cannot compensate for major asymmetry of airflow from the rotor on one wing to the other. Such problems occur when one rotor enters or leaves the vortex ring state before the other, and when in ground effect the flow symmetry is destroyed by proximity to other aircraft disturbing the air or by physical discontinuities of the effective ground surface.
- The aircraft wing design can be optimised without the restraints imposed by mounting engines, nacelles or rotors on the wings.
- The aircraft can be designed for efficient lift in both transition and

helicopter modes by minimising the download from the rotornacelle airflow that acts on the fuselage and wing. This is achieved by ventral fairing of the fuselage, and by aligning the inboard portions of the wing to the airflow. Both methods also provide the possibility of use as control surfaces for the aircraft.

Brief Description of the Drawings

Some preferred, non-limiting embodiments of the present invention will be described by way of example with reference to the accompanying drawings, in which:-

Figures 1 and 2 show front and plan views of a first embodiment of a convertiplane, in the airplane mode, in accordance with the present invention;

Figures 3 and 4 show front and plan views of the convertiplane of figure 1 in helicopter mode;

Figures 5 and 6 show front and plan views of a second embodiment of a convertiplane in accordance with the invention, in airplane mode, and

Figures 7 and 8 show front and plan views of the convertiplane of figure 5 in helicopter mode.

Detailed description of the Invention

With reference to FIGS. 1 to 4, a convertiplane 1 comprises a fuselage 2, a rotornacelle 3 attached above the fuselage 2, and a wing 4.

The rotornacelle 3 supports two rotors 11 that rotate in opposite directions about the common axis A, so setting aside other influences, the force vector produced by the rotors 11 is aligned to axis A. The rotornacelle 3 houses the engines and known devices - not forming part of the present invention and therefore not shown - for transmitting power to and for controlling the cyclic and collective pitch of the rotors 11. In particular the rotors are coupled through a differential gear to equalise the

torque supplied to each, any imbalance relative to axis A manifesting itself as a torque reaction on the differential casing which is transmitted to the airframe. This torque imbalance is cancelled by control of the relative collective pitch of the two rotors, and this also is employed to maintain yaw control of the aircraft in hover mode and at low airspeeds. For this reason it is unnecessary to provide the aircraft with a tail rotor or similar torque balancing system.

The rotornacelle 3 is attached to the fuselage 2 by two actuation devices 20, such as inter-connected geared-down electric motors.. The two actuation devices 20 are used to rotate rotornacelle 3 about the axis B between a helicopter mode where axis A is substantially vertical, and an airplane mode where axis A is substantially horizontal. Each device 20 comprises a load bearing casing, electric motor, fail safe, devices, monitoring devices and a high torque output reduction gearbox. The devices are configured to provide high integrity rotary actuation capable of supporting the weight of the aircraft in hover mode and to achieve translation to and from forward flight in about ten seconds.

The devices 20 may be arranged to provide translation as well as rotation, for example by interposing beams or pivot arms between the axis B and pivotal connections to the nacelle. This may allow a more compact movement between left and forward flight positions. Differential control of the actuators in such arrangement can vector the rotor thrust, perhaps permitting cyclic pitch control to be omitted, or to assist in aircraft trimming, and aircraft CG balancing.

Wing 4 has two halfwings 5, each having an outer portion 6 attached to two fixed beam elements 7, 8 that project from the fuselage 2, so that wing 4 is fixed relative to the fuselage 2 and the outer portions 6 are substantially outside the airflow of the rotornacelle 3.

The aircraft is configured to reduce the detrimental download forces that rotor airflow can create on the wing surfaces within its flow field. The inner part of each halfwing 5 comprises two inner wing portions 9, 10 movable so as to rotate about the

respective axes E1 and E2 of the fixed beam elements 7, 8. In the airplane mode the two inner wing portions 9, 10 are held flush with the outer portion 6 to form a conventional wing. In the helicopter mode, and in the transition mode between airplane and helicopter, the two inner wing portions 9, 10 are aligned substantially to the local airflow so as to virtually eliminate the detrimental download forces of rotornacelle 3 airflow that otherwise would act on wing 4. The drag coefficient of an airfoil at right angles to the airflow may be as high as 2 but is reduced one hundredfold when substantially aligned to the airflow. The inner wing portions 9, 10 may be used as aircraft control surfaces to supplement or take-over from conventional secondary and primary surfaces which progressively lose their effectiveness due to lack of forward airspeed as the aircraft converts to helicopter mode.

For all flight modes the inner wing portions 9, 10 will be aligned substantially to the local air flow i.e to the wash resulting from the rotornacelle and air movement relative to the aircraft. In helicopter and transition modes the purpose is to eliminate download (drag) forces on the wings; in the airplane mode the purpose is to provide lift with minimum drag. Using displacement from alignment also provides aircraft control forces and moments. The most important control uses are as airbrakes in transition mode and as high lift surfaces in slow airplane mode flight. Equally their differential positioning (wing to wing) produces a moment: In hover and transition this may be used for yaw control for example in an embodiment where differential collective pitch is not available. In airplane mode it may be used for roll control.

The inner wing portions 9, 10 may be alternatively removed from the rotor downwash simply by translating them longitudinally (outwardly) of the wing along the beam elements 7, 8. Then they may be accommodated within or overlapping the outer wing portions, or may be deployed beyond them to lengthen the wings. When just the beam elements 7, 8 are exposed to the rotor downwash the downforce on the wing may be reduced tenfold.

Translation of the inner wing portions 9, 10 transversely of the beam elements in the manner of flaps as well as pivoting then enables the inner wing portions to be used even more effectively as left-augmenting and/or flight control surfaces in forward flight and transition, for example by increasing the effective wing area, angle of attack and curvature of the effective airfoil.

Additionally, the download forces associated with air from the rotornacelle 3 flowing downwards around the fuselage 2 are minimised by suitably fairing the underside of the fuselage 2 as shown at 19. Panels set into the fuselage may be deployable for control purposes. For example, in search and rescue and other missions where rope or winch access is needed in hover, panels deployable as symmetrical diverters can be provided at the shoulders of the fuselage so as to disperse the downwash to give calmer air immediately beneath the fuselage. In another example a fin is disposed along the length of the apex of faired portion 19, and is rotatable about an axis at the apex parallel to the longitudinal axis of the aircraft to generate side forces when the aircraft is hovering in a side wind so that aircraft alignment is preserved for VTOL in constrained landing sites, or so that aircraft pointing may be retained for observation, aiming or weapon release purposes. Tricycle landing gear 22 is provided.

A typical flight for convertiplane 1 is envisaged as take-off, climb to chosen altitude, cruise, descent from altitude, and landing. For each phase of the flight the pilot may choose to fly the convertiplane in any one of the helicopter, transitional, and airplane modes, subject to flight regulations and envelope. To illustrate operation of the convertiplane 1, a flight plan will be assumed which starts with a conventional airplane runway take-off, climb and cruise, and then uses the transitional mode for descent, and lands using the helicopter mode.

In preparation for take-off the rotornacelle 3 is aligned substantially horizontally and remains thus through take-off, climb and cruise. The rotornacelle 3 may be trimmed in this conventional airplane mode to optimise the aircraft's attitude for efficient flight and for CG balancing. Descent is entered by reducing forward speed to the point where the desired rate of descent is achieved; this may be by reducing engine

power, use of air brakes or such other conventional airplane primary and secondary control surfaces as provided or by deployment of inner wing portions 9 or 10 as airbrakes, or a combination of all such. At an appropriate distance form the intended landing site, the engine power and the angle from horizontal of the rotornacelle 3 are steadily increased and forward speed further reduced, by means as just described, so entering the transitional mode. The transition continues until the rotornacelle 3 is aligned substantially vertically, and the convertiplane has thereby entered the helicopter mode and is landed as such. Throughout transition and helicopter modes the inner wing portions 9 or 10 are substantially aligned to the local airflow and are able by use of small deflections to produce significant forces to assist change of aircraft forward speed, change of wing lift and change for control and manoeuvring.

Vertical take-off and transition to forward flight is essentially the reverse of the forward flight to hover transition and vertical landing described above. In hover and in forward flight at helicopter speeds, cyclic pitch can be used to keep the rotor thrust vector passing through the aircraft CG. At aircraft flight speeds, the horizontal tail control surfaces take over this duty.

Referring to figures 5 and 6, there is shown another embodiment of the invention configured as a pilotless aircraft. Parts already described with reference to figures 1 to 4 carry the same reference numerals.

The aircraft is of a high-wing twin-boom layout, booms 22 extending rearwardly from the inboard end of outer half-wings 6 to support the aircraft's twin empennage 24 and horizontal stabiliser 26. Moveable half wings 5 are provided as in the figure 1 embodiment.

The rotornacelle 3 is pivotally mounted about a transverse axis C at the rear of the fuselage 2. For stability on the ground, tricycle undercarriage 28 with a tailwheel is provided.

In lift (helicopter) mode the rotornacelle is pivoted so as to dispose the rotors below the fuselage as shown in figure 7, the moveable inner wings being positioned to avoid obstructing the flow of air to the rotors. During transition to forward flight the rotornacelle is rotated gradually into the position shown in figure 8 in which the rotors act as a pusher propeller between the booms 22. The moveable portions 9, 10 are progressively pivoted so as to offer minimum drag to the airflow passing through the rotors. The relatively high velocity of this flow over the half-wings assists in generating lift. The portions 9, 10 in this embodiment may in particular be used to control yaw, enabling the relatively complex differential control of collective pitch to be omitted, with attendant cost savings.

The transition from forward flight to helicopter mode is as described for the figure 1 embodiment.

A variant of this embodiment is to mount the rotornacelle above the fuselage on pylons or supports spaced wider than the width of the rotors (for example at junctions between the booms 22 and the wings 4), and sufficiently tall for the tilt axis C to be positioned for the rotornacelle to move from a lift position beneath the axis C but above the fuselage to a flight position behind it. The pylons may be pivotally connected both to the nacelle and to the boom junctions to enable the nacelle to be positioned lower in the forward flight position, with its thrust vector passing closer to the aircraft CG.

While the present invention has been described in connection with certain preferred embodiments, it is to be understood that the subject matter encompassed by the present invention is not limited to those specific embodiments. On the contrary, it is intended to include all alternatives, modifications, and equivalents as can be included within the spirit and scope of the following claims.

For example, the open rotors may be enclosed within a rim or very short duct to form ducted rotors with collective and cyclic pitch as already described.

Alternatively ducted fans with a larger number of blades of fixed or collective pitch may be used. Whilst the duct would bring a cost and weight penalty, a ducted rotor or fan would have less noise from blade vortex interference and possibly reduced susceptibility to vortex ring state.

Instead of being coaxial the contra-rotating rotors may be disposed on spaced axes side by side, so that viewed from the front the rotornacelle appears U-shaped, the engine and tilt axis forming the base and two side-by-side rotor masts forming the sides of the U. The masts would be just over a rotor radius apart and equally spaced about the aircraft centre line, the contra-rotating rotors being geared together so as to intermesh. Alternatively the rotors may co-rotate provided the masts are of different heights or spaced more than a rotor diameter apart. Some means of compensating for torque reaction on the airframe (eg. a tail rotor) then would be necessary.

A further variation is to employ contra-rotating intermeshing rotors with rotor masts close together but at a slight angle to each other symmetrically about the aircraft centre line, so that they present a V-shaped appearance viewed from the front. The rotor masts are canted outwards no more than is necessary for the blades to intermesh with adequate clearance.

A large aircraft may have two separate tiltable contra-rotating rotors, one at the front and one at the rear, each being carried on a tiltable nacelle. Alternatively each rotornacelle may have a pair of contra-rotating rotors.

Each feature disclosed in this specification (which term includes the claims) and/or shown in the drawings may be incorporated in the invention independently of other disclosed and/or illustrated features.

Statements in this specification of the "objects of the invention" relate to preferred embodiments of the invention, but not necessarily to all embodiments of the invention falling within the claims.

Claims

1. A tilt-rotor aircraft comprising a fuselage, wings for sustained forward flight, and at least one rotor tiltable between a position providing lift and a position providing propulsion for forward flight, the rotor or rotors being carried by supporting structure mounted on the fuselage and being disposed on or symmetrically about the longitudinal centre line of the aircraft.

2. A tilt-rotor aircraft comprising a plurality of rotors carried by at least one tiltable nacelle on the longitudinal centre line of the aircraft.

3. An aircraft as claimed in claim 1 of claim 2 comprising a pair of contra-rotating rotors which are coaxial, or on parallel axes, or intermesh.

4. An aircraft as claimed in any preceding claim wherein a said nacelle or supporting structure is mounted to pivot and optionally also translate about an axis extending transversely of an upper part of the aircraft fuselage.

5. An aircraft as claimed in any of claims 1 to 4 wherein the rotors are mounted above the fuselage on a nacelle moveable between a lift mode and a forward flight mode.

6. A tilt-rotor aircraft comprising a tiltable rotor assembly moveable between a lift position and a forward flight position in front of or behind the fuselage.

7. An aircraft as claimed in claim 6 wherein the lift position the rotor assembly is below the fuselage of the aircraft.

8. An aircraft as claimed in claim 6 wherein in the lift position the rotor assembly is above the fuselage of the aircraft.

9. A tilt-rotor aircraft as claimed in claim 6, 7 or 8 being also as claimed in any of claims 1 to 5.

10. A tilt-rotor aircraft as claimed in any of claims 6 to 9 being of a twin- boom layout, wherein booms extend from the wings of the aircraft to support the aircraft's empennage, the rotor assembly being disposed between the booms when the aircraft is in forward flight mode.

11. An aircraft as claimed in any preceding claim wherein at least inboard portions of wings of the aircraft are moveable so as to present leading edges to the airflow generated in lift mode.

12. A tilt-rotor aircraft comprising a tiltable rotor assembly on the longitudinal centre line of the aircraft moveable between a lift mode and a forward flight mode, inboard portions of the wings of the aircraft being moveable so as to present leading edges to the airflow generated by the rotor assembly in lift mode.

13. An aircraft as claimed in claim 11 or 12 wherein a said moveable portion is rotatable and/or translate longitudinally or transversely about a fixed beam projecting from the fuselage of the aircraft.

14. An aircraft as claimed in claim 13 wherein the beam extends to a fixed outboard portion of the wing.

15. An aircraft as claimed in any of claims 11 to 14 wherein each wing has at least two substantially parallel moveable portions.

16. An aircraft as claimed in any of claims 11 to 15 wherein a said moveable portion is configured to act as a control surface when the aircraft is in lift mode and/or in transition between lift and forward flight modes, the aircraft also comprising control means for operating the control surface.

17. An aircraft as claimed in any preceding claim wherein the underside of the fuselage is shaped to reduce download forces on the fuselage from the airflow generated by the rotor or rotors in lift mode.

18. An aircraft as claimed in any preceding claim comprising a control surface on the fuselage, operative when the aircraft is in a lift mode and/or in transition between lift and forward flight modes.

19. A tilt-rotor aircraft substantially as herein described with reference to the accompanying drawings.

Abstract

A tilt-rotor aircraft comprising a pair of contra-rotating co-axial tiltable rotors on the longitudinal centre line of the aircraft.

(Figure 4 for publication)

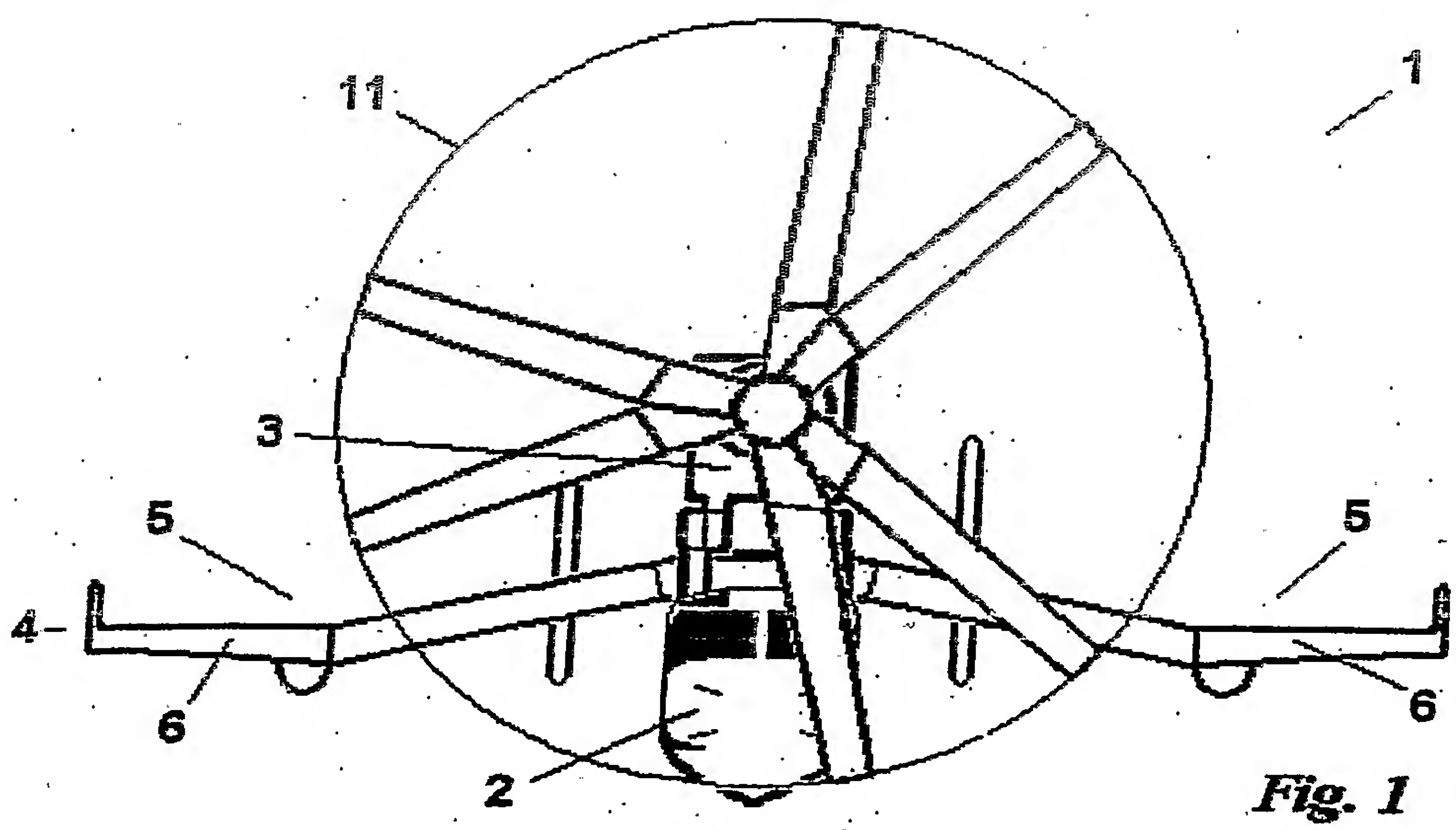

Fig. 1

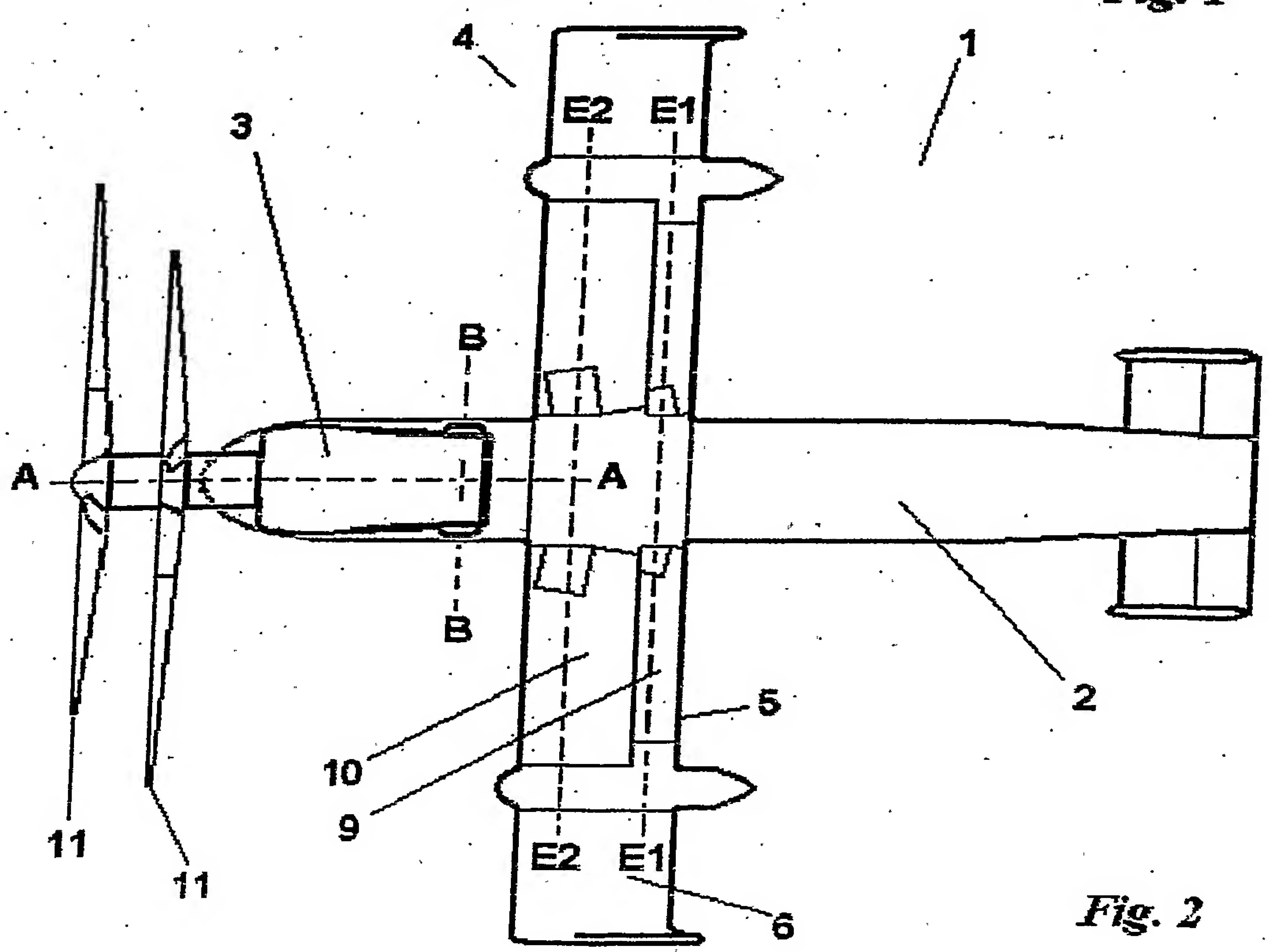

Fig. 2

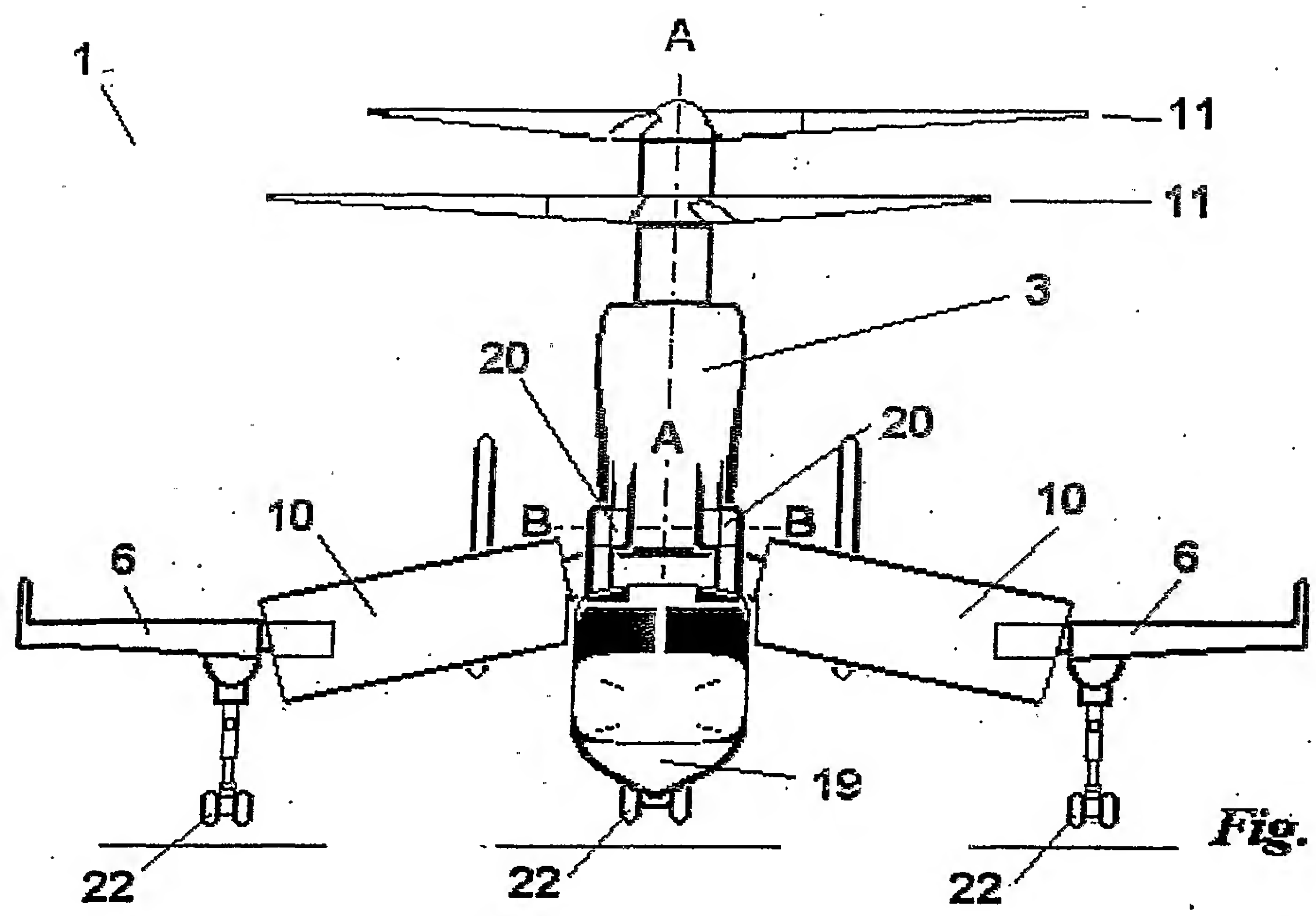
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Fig. 3

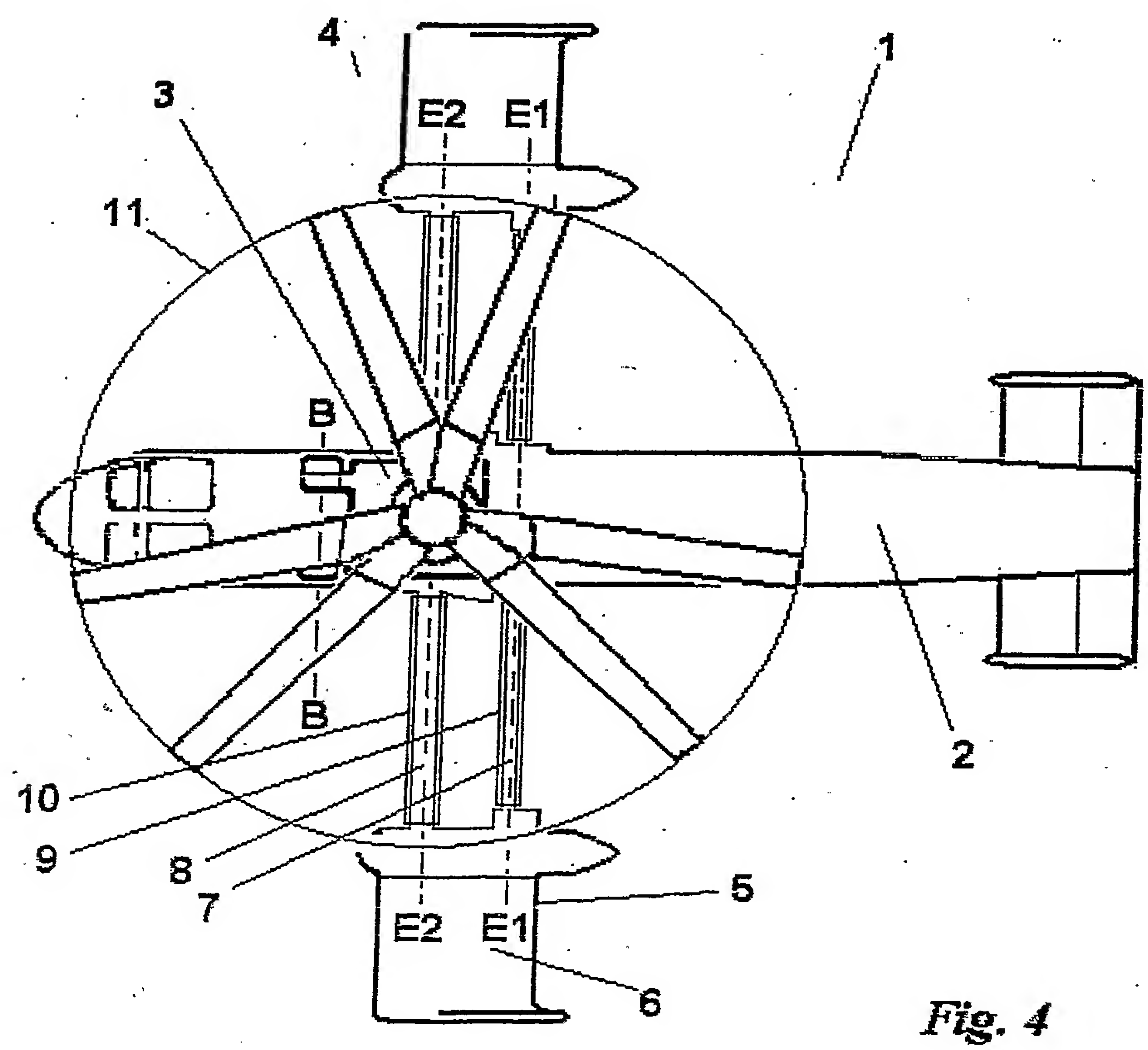
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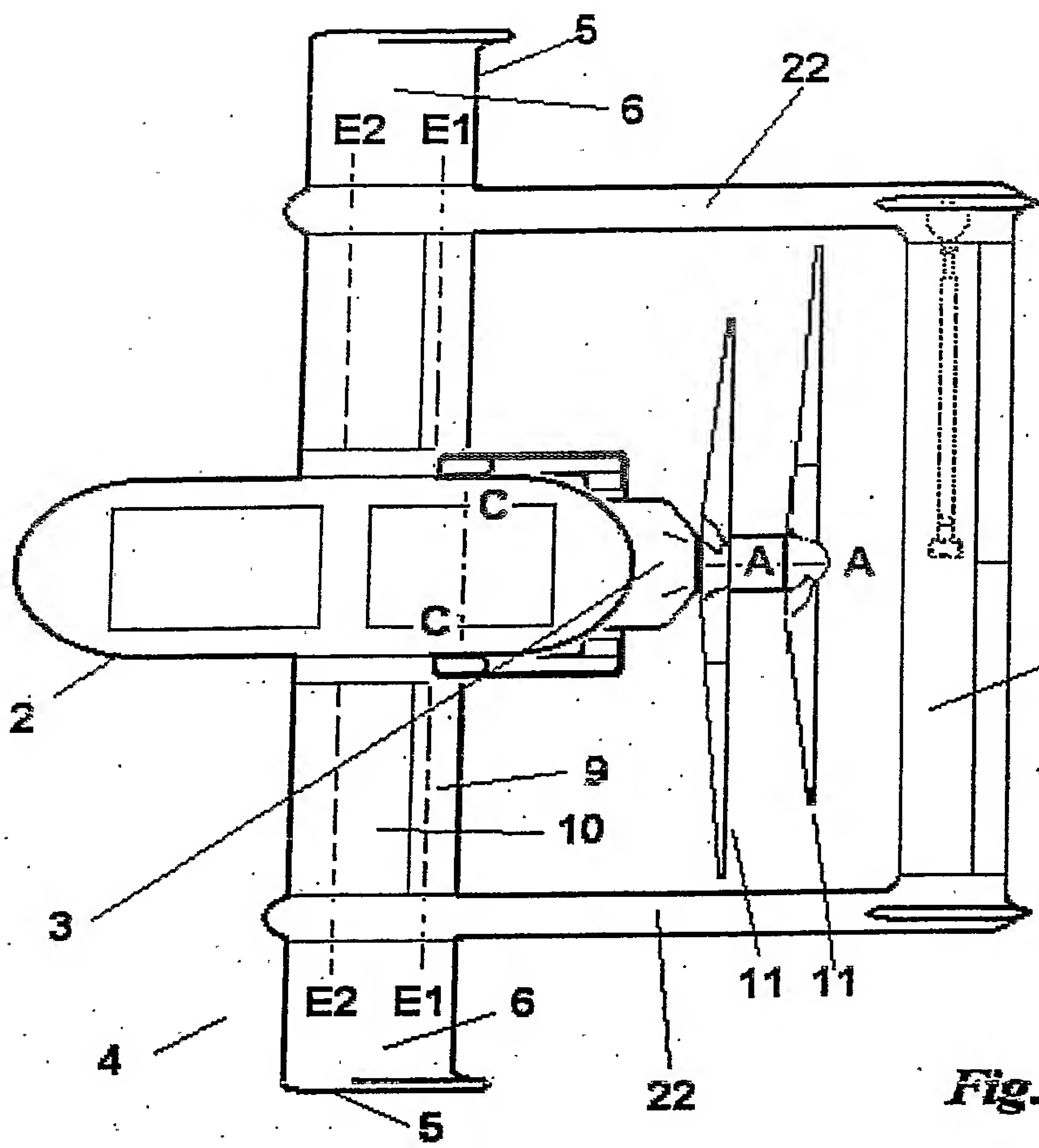
Fig. 4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5

Fig. 5

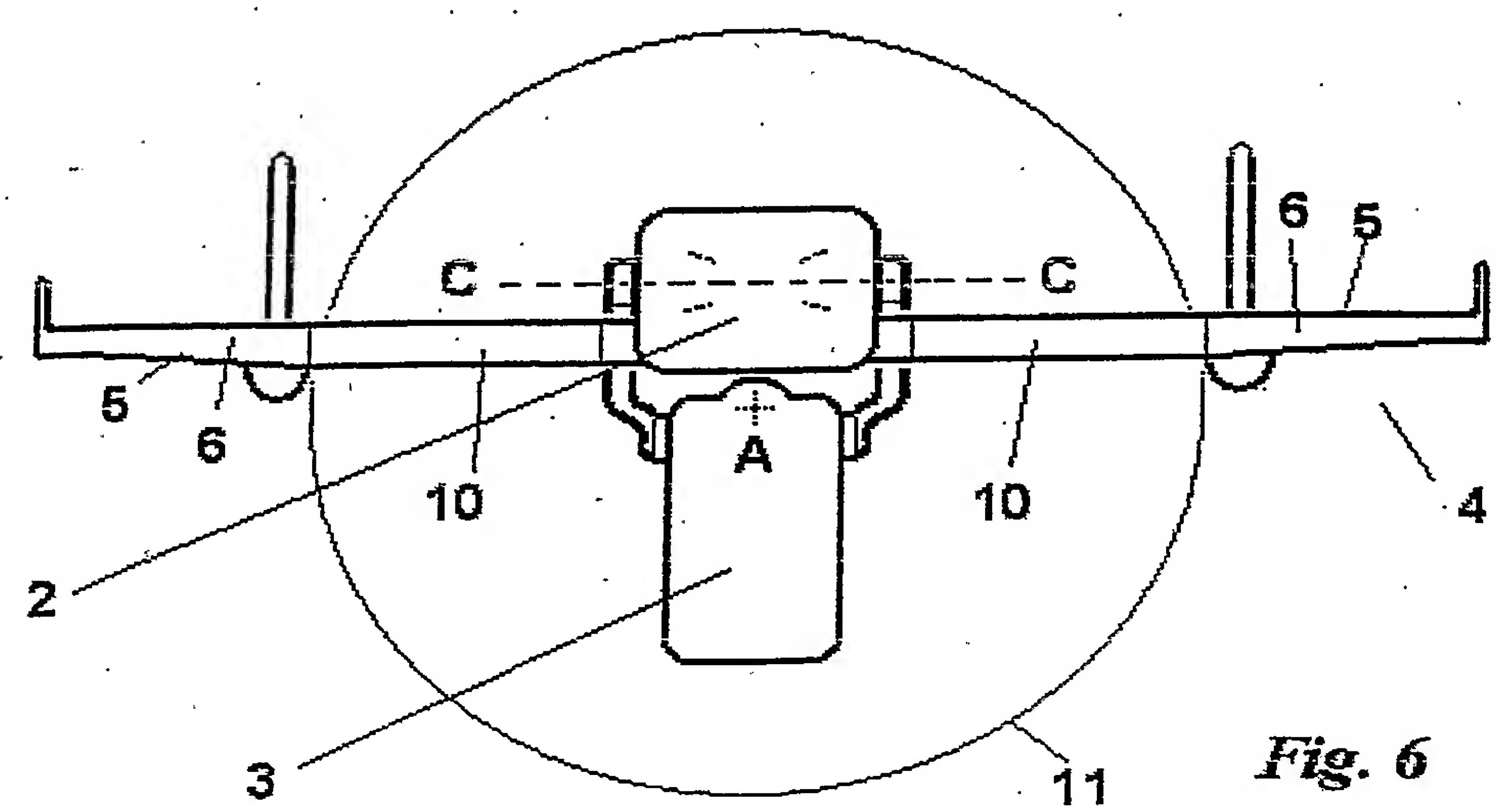
6 5
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Fig. 6

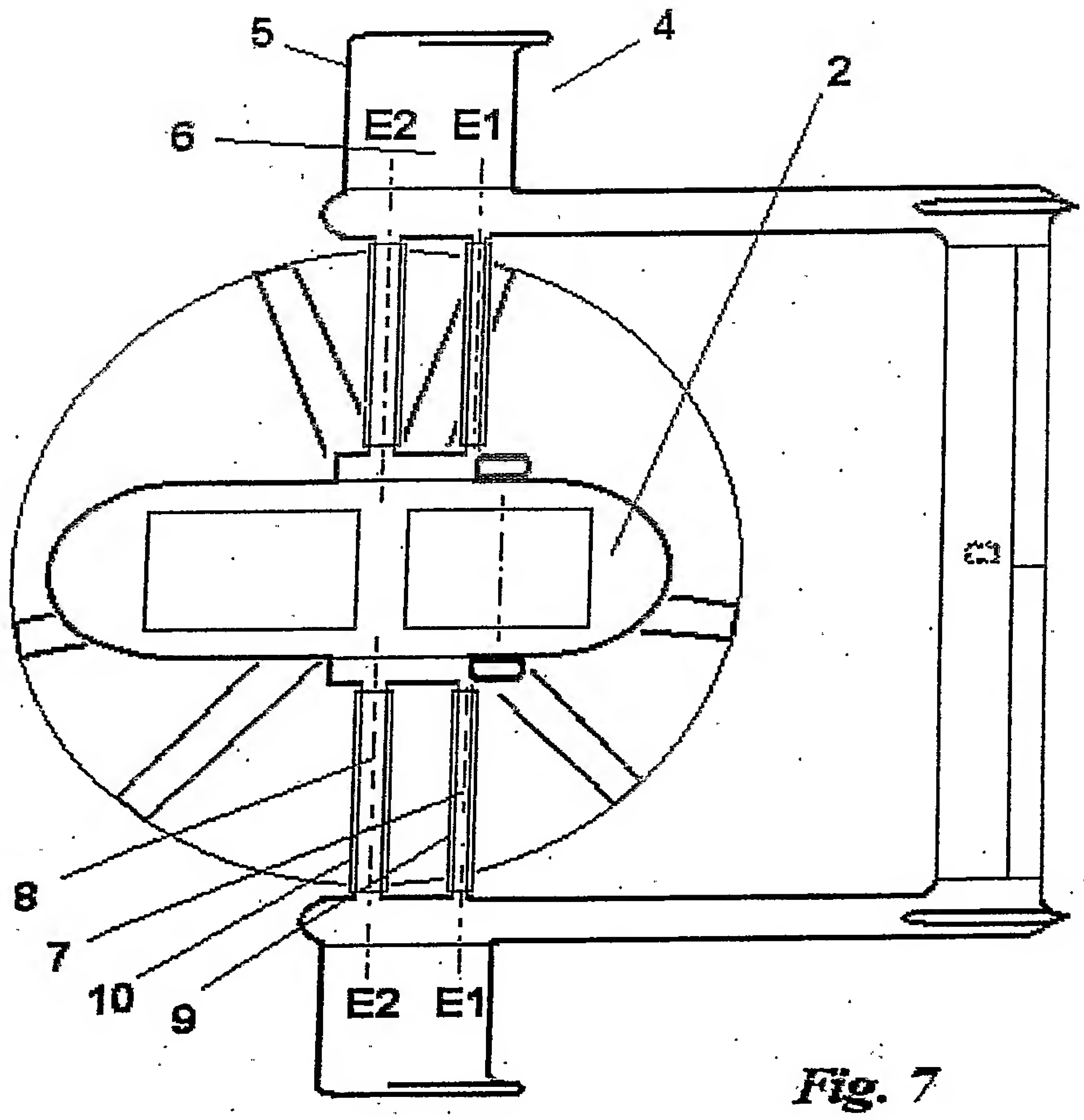

Fig. 7

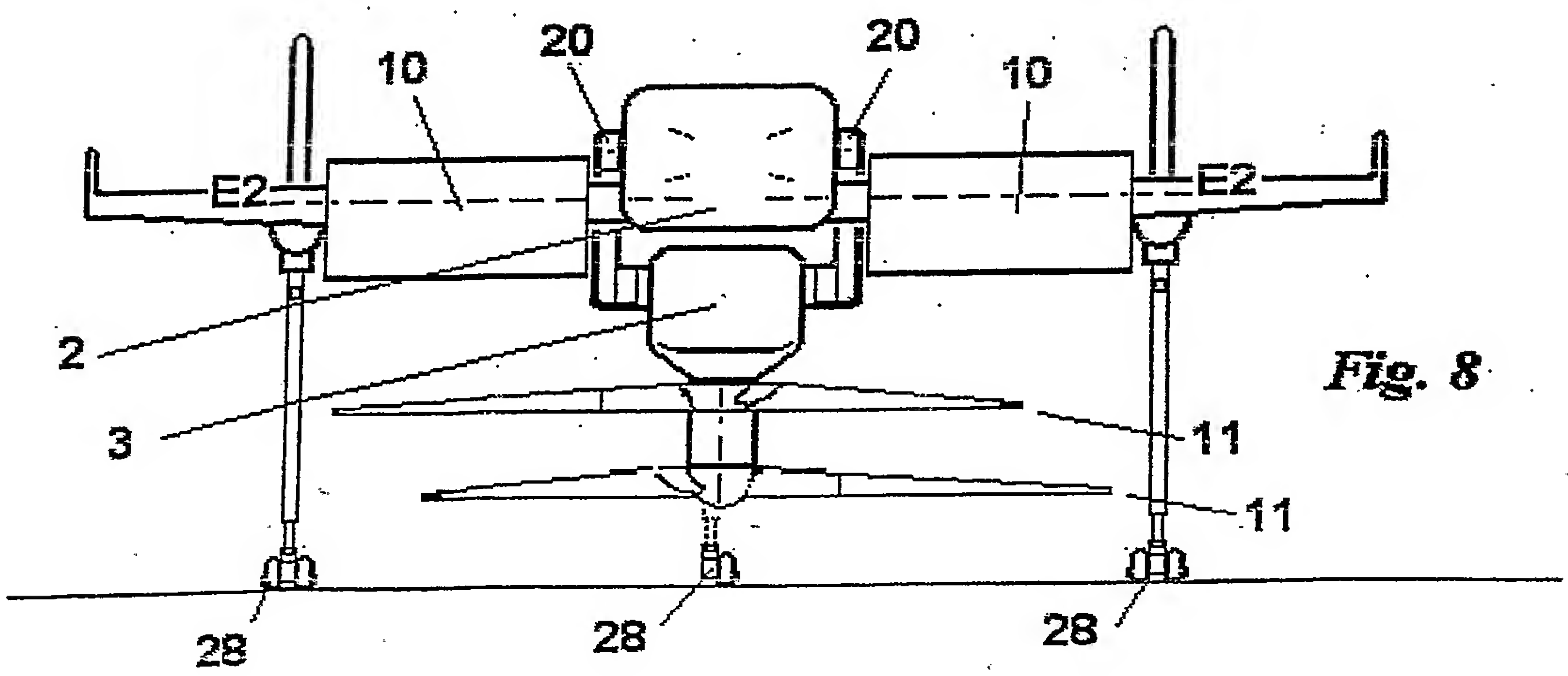

Fig. 8